



# A GEOGRAPHICAL INTRODUCTION TO THE BIOLOGICAL REPORTS.\*

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WITH TWO PLATES AND FOUR TEXT-FIGURES.

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## (a) INTRODUCTORY : THE REEFS.

The "Great Barrier Reefs" extend in a nearly continuous series along the Queensland coast, from Torres Strait in the North to Swain Reefs in the South ; approximately from  $9^{\circ}$  to  $22^{\circ}$  of south latitude. There is a further extension of the reefs to Lady Elliott Island in latitude  $24^{\circ}$  south, to the south-west of the Capricorn Channel. The "Barrier" is not an unbroken line of reef ; only to the north of Cairns does it bear any very close resemblance to the Barrier Reefs of our text-books. In this part there is a chain of linear reefs facing the deep ocean, and intersected by narrow channels.

It is unfortunate that the system as a whole has been called the Great Barrier Reef, for south of Cairns, the so-called "Barrier" really consists of reefs spread over a wide platform, and showing no particular arrangement. The trends of the reef systems do not conform closely with those of the Queensland coast. In the extreme north the line of the outer barrier is some 80 miles from the coast ; traced south to Cape Direction ( $13^{\circ}$  S. Lat.), the outer reefs close with the coast, where their outer limit is only about 15 miles off shore. From here to the neighbourhood of Cairns ( $16^{\circ} 55' \text{ S.}$ ) the reef system is fairly regular, the outer edge varying between 20 and 30 miles from the coast, the inner edge approaching, at its nearest point, at Cape Melville within 7 miles. From Cairns southwards the "Barrier" progressively increases its distance from the coast, and the reefs composing it form an ever-broadening band. Near Townsville the reefs are about 50 miles away, and Swain Reefs are nearly 100 miles distant ; the "Barrier" here being about 50 miles wide, and consisting of reefs, as yet largely uncharted.

The survey of the reefs is far from complete, but the existing Admiralty charts show their complexities extremely well. The characteristic outer reef zone in the southern part is several miles broad, and consists of an immense number of isolated patches of reef separated by channels, often too intricate and narrow for navigation. In the north

\* Full accounts of the work of the Geographical Section of the Expedition will be found in the 'Geogr. Journ.,' lxxiv, 1929, pp. 232-257, 341-370 ; and vol. lxxvi, 1930, pp. 193-214, 273-297. By permission of the Royal Geographical Society, text-figs. 1, 2 and 3 are here reproduced from the former of these papers.

the outer line of the reef is clearly defined, and there is a steep slope to deep water, the 1000-fathom line being reached in a few miles. There are also wide passages through the "Barrier"; Trinity Opening off Cairns, is a good example. These wide openings, commoner in the southern parts of the reef area, have been associated by some writers with former river channels. There is very little *direct* evidence for this conclusion.

North of Trinity Opening some system may be traced in the reefs *between* the true outer barrier and the mainland. These reefs are isolated patches of varying magnitude, conforming in their general trends with the coast and the outer barrier. These "inner" reefs rise steeply from the floor of the protected sea, and many carry sand-cays on their surfaces. Between these inner reefs and the mainland there is a channel, for the most part free from obstructions, which forms the "Inner Route" for steamers visiting the Queensland ports. In this channel there are occasional "island reefs," which carry, in addition to a sand-cay, accumulations of shingle and a mangrove swamp. These are the Low Wooded Islands of the charts, and it was on one such, Low Isles, that the main expedition had its headquarters.

The individual reefs vary greatly in size and shape, but we may note here one or two *general* points. Nearly all reefs tend to develop a crescentic form, the convexity of the crescent facing the weather. In the case of an outer reef the convexity faces the Pacific; the inner reefs are convex to the south-east Trade. The reefs of the northern part of the outer barrier are long and narrow, their major axes running more or less north and south. Ribbon Reef is about 14 miles long. At their extremities they nearly always show landward-directed turns, thus conforming to the general crescentic form. Cairns and Arlington reefs are fine examples of reefs in which the convexity is directed south-east. Smaller reefs do not always show this appearance on the charts, but Low Isles, for example, shows an anchorage on the leeward side of the reef between the horns of the crescent. When the reef is exposed at a spring tide, this anchorage appears as a north-facing gulf or bay.

The protected sea which contains the detached reefs, is less than 200 ft. deep, except very occasionally in straits between high islands. Its floor is relatively very flat and covered with sediments derived from the mainland, islands and reefs and redistributed by marine agencies. As a rule, the increase in depth of this enclosed sea is gradual from the coast to the outer barrier, the average depth in the steamer channel being 15 to 20 fathoms.

The study of these numerous reefs is an enormous problem, mainly biological. The work of the Expedition, however, has amply demonstrated that much valuable work, in the way of careful surveys of the reefs and their debris accumulations, has yet to be done. Largely on account of physical difficulties this has not been attempted, but the time has come when a close and friendly alliance between workers in *all* sciences concerned with coral reefs is not only desirable, but necessary.

#### (b) THE PLATFORM ON WHICH THE REEFS REST.

It is one thing to describe and account for the biological phenomena associated with coral reefs; it is another to account for their origins. The Australian reefs are no exception. Of late years the tendency has been to go back to the Darwinian hypothesis of subsidence, largely through the work of W. M. Davis.\* The importance of physiographical work is

\* "The Coral Reef Problem," 'Amer. Geog. Soc.,' Special Publication, No. 9, 1923.



undoubted, and although analogies between different reefs and reef areas have much value, the present writer feels that each reef area needs careful individual study. This seems to apply particularly to the Australian reefs, which are developed on a much vaster scale than any others in the world.

In the scope of the present paper all that will be attempted is a short summary of some of the major problems relating to the origin of the reefs, or—what comes to the same thing—of the origin of the platform on which they are based. This will be followed by some generalized accounts of recent fluctuations of sea-level, and by a short summary of the main features of the high and low islands associated with the reef area, in so far as these problems affect the main point at issue.

A full discussion of the various hypotheses which have been put forward to explain the origin of the Australian reefs is out of place in these reports, and will be found in the reports of the Geographical Section of the Expedition published in the 'Geographical Journal' (see foot-note, p. 1).

The following account is designed to form a framework by which the biological work of the major part of the expedition may be related to the difficult problem of reef origins.

There have been many speculations as to the origin of the Queensland reefs, and, in brief, one may say that there are two schools of thought: the one regards the coralline mass as thick and as having grown up on a subsiding platform; the other thinks of the actual reefs as a comparatively thin veneer on a platform produced in some way quite independent of the reefs themselves. There are naturally variants of these hypotheses *e.g.* those who hold to a considerable thickness for the coral do not necessarily agree amongst themselves about the manner in which subsidence took place. Jukes and others think of a simple sinking of the Queensland littoral much in the manner Darwin postulated; others—and this is perhaps more typical of recent writers—think of warping, or founderings resulting from faulting of the eastern margin of the continent.

That submergence, to some extent, has taken place there is no doubt. The physio-graphical evidence of the drowned valleys and certain borings on the mainland prove this. But a difficulty arises because submergence of a restricted amount can be explained without having recourse to the great downward movements such as are usually implied when thinking of the subsidence theory of coral reefs. It is probable that the relative level of land and sea oscillated through a range of some 200 ft. or more in the Quaternary Ice Age. Further, there is reason to believe that the Australian reefs are pre-Glacial in origin. If, then, we assume sea-level fluctuations of this sort in Quaternary times, and at the same time postulate (*cf.* Daly's Glacial Control Theory\*) a lowering of ocean temperature, we may conceive of low level Pleistocene abrasion wholly or partially destroying any pre-Glacial reefs and cutting a platform not only around Queensland, but elsewhere. On this platform when both the temperature and level of the ocean rose once again, coral colonies grew and produced the reefs as we now know them.

But there are grave difficulties against accepting such a theory *in extenso*. Low-level abrasion of this sort clearly implies the production of cliffs. Cliffs are not entirely absent from the mainland coast and high islands within the barrier reefs. But what cliffs do exist are only of such magnitude as could be produced by the waves of the protected seas within the reefs. On the other hand, if there has been a post-Glacial rise of sea-level

\* Daly, 'Proc. Amer. Acad. Arts Sci.,' li, 1915, pp. 155-251, and 'Amer. Journ. Sci.,' ser. 4, xli, 1916, pp. 153-186.

the cliffs which were produced at low levels are now drowned and probably buried by sediments, and it is highly doubtful if any evidence can be found for their existence.

However, apart from this difficulty, there are others of equal or greater magnitude. The great width of the platform on which the Australian reefs rest is, in itself, a strong argument against its complete production by low level Glacial abrasion. Also, it is not easy to see why there should be so many high or continental islands left standing as there now are if one assumes planation to this extent. Again, as Davis pointed out, any theory which regards the reefs as independent of, or subsequent to, the platform is faced with two difficulties—why should there be a long interval in time between the formation of the platform and the building of the reefs, and why should reefs only grow after the platform was formed?

But to argue against the probability of low-level abrasion in producing the platform is not to deny oscillations of sea-level. The evidence of the drowned valleys, etc., of the Queensland coast points to a relatively recent rise of sea-level of the order of 200 ft. We may take this as a post-Glacial rise. (It will be seen later that this is not the last movement of this type which has affected Queensland.)

A study of the geology and physiography of Queensland and the adjacent continental shelf south of the Cape York Peninsula shows clearly the importance of trend lines whose mean direction may be taken as north-north-west. Such trends are seen in many parts of the actual coast-line, in the various hill ranges, collectively grouped as the Coastal Ranges, in river courses, in lines of high islands and in certain parts of the reef area, *e.g.* the Capricorn Channel. Australian geologists have shown that such trends are approximately coincident with known anticlinal axes of Mesozoic Age and Tertiary fault lines. Sir T. W. E. David,\* Prof. H. C. Richards and the late Charles Hedley,† W. H. Bryan,‡ D. R. Jardine§ and G. V. Stanley|| have called attention to the coincidence of fault lines with the present coast. Our own observations on the physiography of the coast, especially north of Cairns, bring us into line with this point of view.

In the Cape York Peninsula, Richards and Hedley claim that faulting has controlled the main outlines of the coast. But here the faulting has been rectangular, the main directions being east-west and north-south. A glance at the map (text-fig. 1) will make this point clear.

Other evidence for vertical movements is shown by the great gorges of the Barron and other rivers. These, in themselves, merely prove upward movement of the land, but it is highly probable that such movements, taken in consideration with the strongly faulted appearance of the mainland coast, especially north of Cairns, were accompanied by downward movements of that area which now lies beneath the protected seas.

The high or continental islands, which exist in large numbers between the reefs and the mainland, are frequently in lines, as already noted, approximating to the north-north-west trends, and show physiographical evidence of recent submergence. Such evidence of submergence as they show could possibly be explained by the recent sea-level rise of about 200 ft. But their physiographical evidence, and geological similarities to

\* 'Journ. Roy. Soc. N.S.W.,' xlv, 1911, pp. 4-60.

† 'Reps. Gt. Barrier Reef. Comm.,' i, 1925, pp. 1-28.

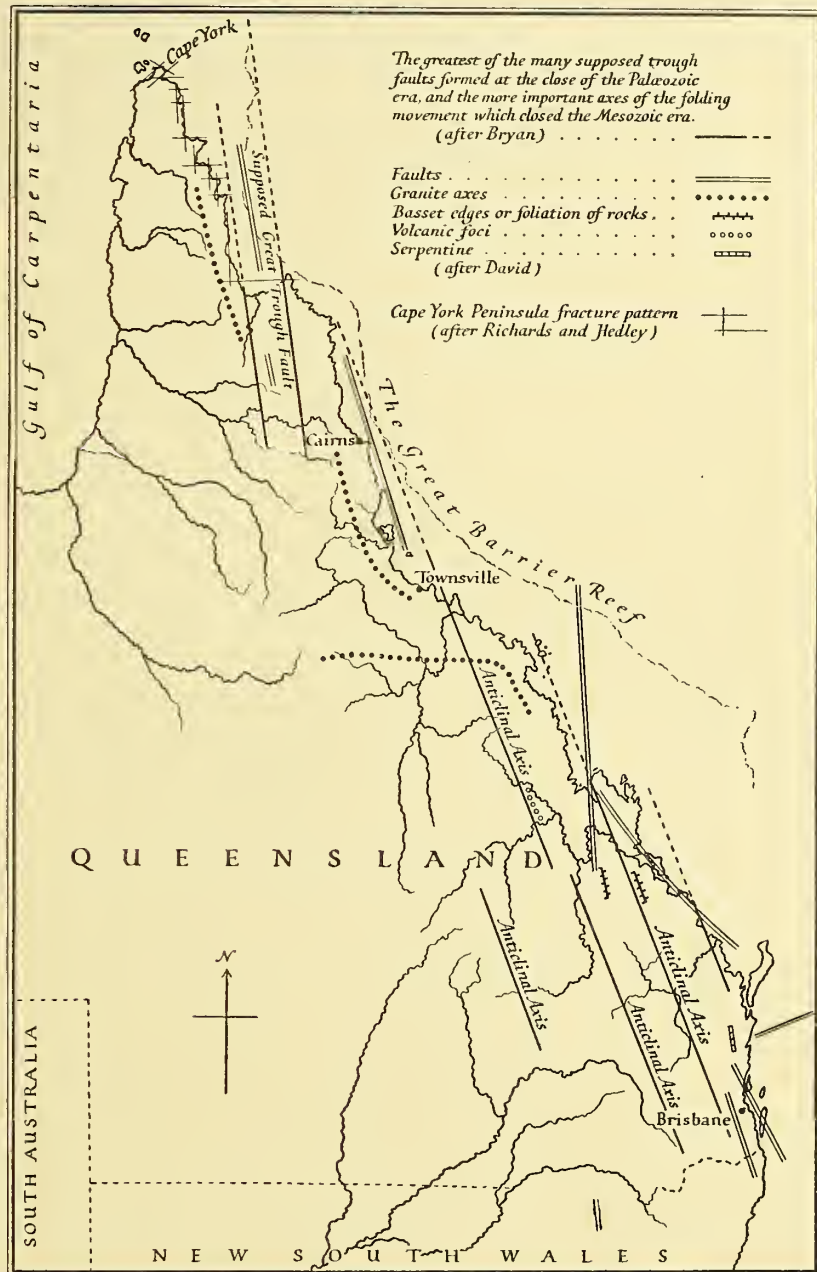
‡ 'Proc. Roy. Soc. Qd.,' xxxvii, 1925, pp. 1-82 (Pres. Address).

§ 'Reps. Gt. Barrier Reef Comm.,' i, 1925, pp. 1-51.

|| *Ibid.*, ii, 1928, pp. 73-110.



those parts of the mainland adjacent to them, suggest that they were separated from the mainland by a considerable submergence. Their actual appearance, as well as the strong suggestion obtained from a chart, leaves little doubt that they are partially drowned hill or mountain ranges.



TEXT-FIG. 1.—Tectonic lines in Queensland.

We thus arrive at the following position: Evidence seems to point to a recent submergence of the order of 200 ft., but, for the reasons given above, we can hardly think of the platform as having been cut entirely by low-level Pleistocene abrasion. If we consider the Tertiary tectonic movements which are known to have affected the eastern littoral of Australia, we have reasons for thinking that the downward movements which have affected the reef platforms have been considerable. At this point we come to a check.

In the present state of our knowledge we can only obtain direct evidence of subsidence by means of deep borings through coral reefs. Perhaps refined geo-physical methods of the future will allow us to obtain evidence of a reef's foundation more easily, but at present expensive borings alone are available. One of these bores was put down in 1926, on the larger cay on Michaelmas Reef. The result was rather disappointing. The cores have not yet been worked up. The bore reached a depth of 600 ft., and "The log shows that apart from a few feet of solid material, the coralline material was loosely coherent, that it extended to a depth of 427 ft., and that beneath this (apart from a little sand recorded from 477 ft.) down to a depth of 600 ft. there was nothing other than rounded quartz with abundant foraminifera, and shell fragments with much glauconitic material."

Hence we are left, unsatisfactorily, in the position of having to speculate upon the nature of the platform on which the reefs rest.

Andrews\* is of the opinion that a peneplain was developed in Eastern Australia in the Eocene and Miocene periods. The present configuration of much of the Queensland coast bears out this point, and we may assume that this peneplain once existed over that part which is now covered by the reefs and protected sea.† It seems, then, that we must assume one of two things: either there has been a warping or flexing movement which has brought down this eastern part of the peneplain below sea-level, or that it has been faulted down. Which of these two views is more probable is largely a matter of opinion. The writer feels that the case for faulting, more or less parallel to the mainland shore, is stronger in view of the known evidence for Tertiary faulting in many parts, and also because the coast, especially to the north, has a faulted appearance. It would, however, be wrong to press this point too strongly.

But whichever view is taken, there is no need to assume that the downward movement has been equal in all parts of the Barrier area. There is also another difficulty: the shelf off New South Wales appears to be the unbroken continuation of that off Queensland, and presumably the two have much in common in their formation.

Another interesting point is that between Trinity Opening and the southern end of the Barrier Reefs, the 1000-fathom line, as far as can be seen from the general charts, runs far out to sea so as to include Osprey Reef, Diane Bank, Willis Islets, Lihou Reef and Cays, Marion Reef and Saumarez Reef. The 100-fathom contour includes Swain Reefs, and then conforms more or less with the general direction of the Queensland coast, and in the north follows closely the outer edge of the Barrier Reefs proper. From Osprey Reefs southwards to near Trinity Opening there is a deep water gulf of more than 1000 fathoms. Thus, the continental shelf of central Queensland, instead of falling steeply at the 100-fathom line to great depths, descends comparatively gently into a great protuberance enclosed within the 1000-fathom line, and for the most part covered by water less than 600 fathoms deep. The significance of this is not clear.

We must also notice another feature. If we do not assume a downward movement of the peneplain everywhere of the same amount, we must try to find an explanation of the more or less constant depth of the protected sea. It is probable that this may be associated with sedimentation. Daněš‡ and others have pointed out how much material

\* 'Journ. Roy. Soc. N.S.W.,' xlv, 1910, pp. 420-480; and 'Proc. Linn. Soc. N.S.W.,' xxvii, 1902, pp. 146-185.

† For arguments on this point see 'Geogr. Journ.,' lxxiv, 1929, pp. 232-257, 341-370,

‡ Ann. Géogr., xxi, 1912, pp. 346-363.



has been deposited within the lagoon from rivers, currents and other sources. The re-distribution of this material by marine agencies has almost certainly led to the equality of depths within the lagoon, and so in this way, even if the faulting or warping movements were unequal in their first effects, these inequalities are now no longer apparent, and we have the smooth-floored lagoon (apart from local exceptions near high islands), seen so well on the Admiralty charts.

It is regrettable that the basis on which a reef rests must largely be a matter of inference. It is, perhaps, the reason for the divergent points of view of biologists and geographers. The former are dealing with definite facts; the latter have too often to deal with theory. In so far, then, as the Australian reefs are concerned, we cannot go much further than saying that it is probable that they rest on a down-faulted or down-flexed peneplain of early Tertiary age, and composed of pre-Tertiary rocks, which once extended to the relatively steep declivity outside the outer Barrier Reefs. Later there were oscillations of sea-level associated with the Quaternary Glaciation, and apart from minor post-Glacial negative movements of sea-level, the last major phase was a positive movement amounting to about 200 ft., giving us the typical drowned valleys of New South Wales and Queensland.

No one is more aware than the writer that this leaves many points unexplained. The platform is of very variable width, especially in the south, where is the great indentation of the Capricorn Channel. Again, the evidence for faulting here is not so striking. In the north, the outer Barrier corresponds fairly well with the outer edge of the platform; in the south the reefs are more broken and scattered and no longer coincide with the margin of the platform nor can they, under any circumstances, be called "Barrier Reefs." In the present state of our knowledge it is not advisable to discuss the problem further in this place. The platform always has been, and for a long time will be, the centre of many theories, but, until we have much more detailed knowledge of the geology, in the broadest sense of the word, of Eastern Australia, and until we know much more about events in Quaternary times, and until Geophysics can tell us more about the probabilities of subsidence on a large scale, we must be content to leave the matter. Enough, however, has been said to make it clear that *no* simple explanation of the platform on which the corals, and so the biologists, have to work is forthcoming.

#### (c) RECENT RELATIVE MOVEMENTS OF SEA-LEVEL.

Mention has already been made of a relative movement of sea-level since the 200-ft. submergence. This last movement seems to have taken place in two stages of limited extent. Along the mainland coast of Queensland, and on some of the high islands, are traces of platforms of marine abrasion some eight feet above present mean sea-level. It is generally conceded that these fragmentary erosion surfaces point to a rise of the land, relative to sea-level, of some 18 to 23 ft. They have been noted by several writers, especially by Hedley. As these traces occur at much the same level, at widely separated places, we probably have to deal with a negative movement of sea-level, rather than with local land movements. This suggestion is strengthened when we note a lower platform more or less flush with the level of high-water neap tides. This lower platform is found all along the east Australian coast, within the Barrier area as well as far to the south in New South Wales. It is not the place here to enter into a discussion of the levels

at which such platforms are cut ; suffice it to say that writers differ a good deal in their views on this point. But there is a general consensus of opinion amongst those who know the occurrences of this platform in Queensland to ascribe it to a slight negative displacement of sea-level amounting to 12 + ft. or thereabouts. In other words, it appears that the total negative movement which has left these *two* platforms visible amounts to about 18 to 23 ft.

If such a conclusion be valid, it must have had interesting effects on the reefs themselves. How far this effect is demonstrable it is very difficult to say. But one or two points bearing indirectly on this problem must be noted. In the coral seas, beach sands and shingle are frequently cemented to form beach rock and coral-shingle conglomerates. Now on many islands, both high and low, such formations often occur at heights strongly suggestive of recent uplift, at least corresponding to the lower terrace of the mainland. Such occurrences are well seen on Houghton Island, Howick Island, Middle Island, Stone Island and many other places. These platforms are now being destroyed by marine erosion. If such uplifts have affected the low wooded islands of the protected sea, it is only reasonable to expect that the reefs themselves have been involved. It is, therefore, pertinent to draw attention to a point mentioned by M. A. Spender,\* who gives reasons for believing that certain types of debris accumulations characteristic of the island reefs are possibly referable to this movement, which has elevated certain reefs so that shingle ridges (or ramparts) might be formed on them. Such a case is Low Isles. There remains, however, the difficulty of explaining why all inner reefs have not been equally affected. It is doubtful if this point can be answered, and the suggestion that such patches of reef, before the presumed fall in sea-level took place, had not all reached equal heights, clearly leaves us in as great a difficulty as before. The suggestion, however, stresses an important point. We need *precise* work on these reefs, work which will give us accurate maps of their surface structure (*cf.* the maps of Low Isles and Three Isles by Spender), and which will give us accurate measurements of mean sea-level. As experiments carried out during the Expedition amply showed, this is not an easy task, but it cannot be emphasized too strongly that such work is necessary. Whether or not this can ever be done on the outer Barrier remains to be seen, but until it is, it is extremely difficult to see how one can, if at all, say whether and how the outer Barrier has been affected by this negative movement. It is relevant at this point to note that certain reefs fringing the mainland, *e. g.* those near Port Douglas and Donovan Point, seem to have been exposed by this movement, and that their upper surfaces are now quite dead in so far as coral growth is concerned.

#### (d) THE HIGH OR CONTINENTAL ISLANDS.

Most of the islands within the Barrier belong to this category. A detailed account is out of the question, and only certain general matters need be mentioned.

They are formed of rocks in every way similar to those of the mainland, and are severed and partially drowned parts of the continent, pointing to a time when it extended to the east of its present limits. Some of these islands, or groups of islands, have been studied in detail by previous investigators, to whose accounts we must turn in order to see how the study of these islands bears on the general problem of the origin of the Reefs.

Most of these islands are covered with dense rain forest which may come down to

\* 'Geogr. Journ.,' lxxvi, 1930, pp. 193-214, 273-297.



within a few feet of sea-level and continue to the summits, often more than 1000 ft. high. On the other hand, some islands have relatively few trees. Why this is so is not quite clear. Usually, between Townsville and Cairns, at any rate, islands of igneous rock seem to be rather more densely forested than others. The islands of metamorphic and sedimentary rocks farther north are often less densely forested, particularly in the Flinders group, which is formed of sandstone. In these northern parts the strong and persistent Trade must make it difficult for forest vegetation to thrive on the weather side of islands. In the south of the Barrier area the Whitsunday group is well forested, at any rate, on the slopes facing the mainland, but many other islands, *e. g.* the Beverley Islands, are grassy on their windward slopes.

“Many of the larger islands show evidences of dissection very clearly. They are cut up into deep valleys which radiate out from a single peak, or, if the island be elongate, the valleys furrow the longer sides.”\* These features have been well described by Stanley in the Whitsunday Islands. The most magnificent of the high islands is Hinchinbrook, about 70 miles north of Townsville, which has several peaks rising to more than 3000 ft. “There are deep gullies between these peaks. . . . It stands up as a great mountain mass, nearly equal in height to the mountains on the adjacent mainland. It is separated from the mainland by a narrow but deep and picturesque channel, now much contracted by mangroves fringing the mainland and the island shores of the channel. The island itself is divided by a low and broad valley into two parts, the southern, apparently largely of granite, being the higher and bigger. Here the peaks are truly mountainous and rugged, and afford the finest coastal scenery in the Barrier region. The northern part of the island contains Mount Pitt, a peak which reaches 2350 ft., but the outlines are less bold and rugged. This deep valley may be a structural feature, but not much is known of the geology of the island, and its densely forested nature makes it difficult to explore. However, the striking differences in profile between the northern and southern parts strongly suggest some differences in rock composition. . . .”

The seaward ends of the valleys and gullies of these high islands are nearly always filled with alluvium and silt, with forests, or mangrove swamps. In some cases (*cf.* Hinchinbrook) the mangroves form a nearly continuous border, and we may possibly have here another line of evidence pointing to the recent negative displacement of sea-level referred to above.

The slopes of many of these islands often continue unbroken to water-level, and when looking at a group of such islands, one cannot fail to be struck by their close similarity to drowned mountain ranges. The Palm and Whitsunday groups show this very clearly. Smaller islands stand up above the water as more or less rounded knobs, *e. g.* the Family Group. Some of these islands merely fringe the land, others, *e. g.* the Palm and Lizard groups, stand well away. North and South Direction Islands and the Lizard group are probably the most isolated, the nearest point on the mainland being some 16 miles distant.

The degree of cliffing to which these islands have been subjected is only moderate. Some of them are uncliffed; others possess minor bluffs, whilst a few are well cliffed. As noted above, the cliffing is only of such degree as could be caused by lagoon seas.

Flinders Islands, made of sandstone, show cliffing quite well. They are also rather

\* Lines enclosed within inverted commas in this and the following sections are taken from the writer's account in the ‘Geogr. Journ.,’ lxxiv, 1929, pp. 232–257, 341–370.

barren and bleak. It has been shown\* that they form part of an anticline which has been ruptured, the line of rupture being marked to-day by Owen's Channel.

Many islands possess fringing reefs: these, in their turn, have served to protect the islands from marine erosion.

It is obvious from a chart that many high islands are in lines, but such lines are not necessarily of structural significance. In some cases they are, as has been demonstrated by Stanley and Jardine in the Whitsunday and Keppel Bay islands respectively. Text-fig. 2 shows clearly the dissected nature of the Whitsunday group, and also the trend lines which Stanley has found in them. The detailed study of these islands is largely a matter of geology, but physiographically the degree of dissection they have attained, their "drowned"



TEXT-FIG. 2.

appearance, their trend lines, their benches, their cliffs, their mangrove flats and other features throw much light on their past history, and incidentally on that of the platform on which they stand.

(e) (1) SAND-CAYS AND (2) LOW WOODED ISLANDS.

The "low islands" of the Reef area are of two types. The one consists of mounds of sand, known as cays, usually found on reefs situated near the outer barrier, the other we may call "Island reefs." These consist of a sand-cay on the leeward side of a reef, with an accumulation of shingle ridges, forming dry land and sheltering a mangrove swamp on the weather side of the reef.† These are the Low Wooded Islands of the Admiralty charts, and are found in, or near, the Steamer Channel (see p. 2). They do not appear to occur south of Trinity Opening, so that Low Isles is the southernmost of the series.

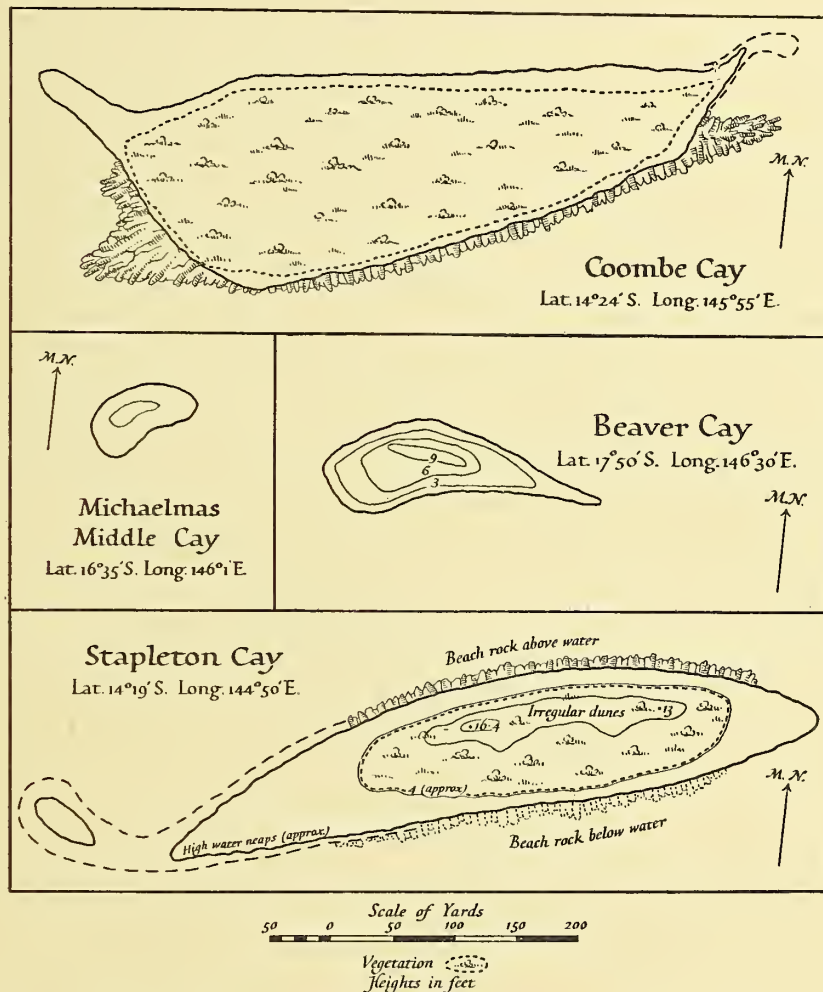
\* Richards and Hedley, 'Reps. Gt. Barrier Reef Comm.', i, 1925.

† The shingle ridges (ramparts) are usually best developed on the windward side, but may extend so far to leeward as almost to meet the sand-cay.



(1) SAND-CAYS.—These simple cays are merely flat heaps of coral sand piled up on individual reefs. Their size and general appearance is shown in the accompanying figure of some typical examples. They do not usually exceed 4 or 5 ft. in height, above high water springs, and many are lower. In fact there is no real difference between a sand-bank awash at low water and a fully-developed cay.

Such structures are unstable, and vary a good deal in shape and size from time to time, with the varying incidence of wave-attack. Observations made on Beaver Cay\* show how



TEXT-FIG. 3.—Typical Sand-cays.

easily and rapidly such changes take place. As a rule the cays are flat-topped, but in some cases vegetation has led to the growth of dunes and then the cays are higher and more irregular. The relations between vegetative and physical factors in the formation and growth of these cays is a matter which would repay full investigation. Some of the cays are entirely devoid of any plant life, others, *e. g.* Green Island, off Cairns, are large and well forested. There is every transition between these two extremes. However, the characteristic cay is usually covered by low shrubs, creeping plants or grasses, which have

\* Beaver Cay, 'Qd. Geogr. Journ.,' xxxix (contribution No. 2, 'Reps. Gt. Barrier Reef Comm.'). Similar changes seem to have taken place on Pixie Reef.

led to the formation of dunes. Such cays, *e. g.* Michaelmas Cay, are usually the haunts of numerous birds. Once vegetation has obtained a hold the cays are rendered rather more stable. Another factor in their stability is the formation of beach rock around them. It is worth noting here that in all the cays we visited we did not find one in which there was beach rock\* and no vegetation.

The position of the cays on the reefs on which they stand is important. Those which we visited were situated near the western or north-western end or leeward side of a reef. The longer axes of these cays were often oriented from a point rather to the north of east to one south of west, their longer axes being thus approximately at right angles to the prevalent south-east winds.

The coral sand which forms the cay is clearly the product of wave erosion of the reef on which the cay stands. This abraded material tends to be swept across the reef, mainly to the north-west. In many cases, doubtless, most of the material is swept completely over the surface of the reef, but in others another factor comes in. On the leeward side of some of the reefs the waves from the south-east often "wrap round" the reef, and the meeting of the two sets of waves is then instrumental in obstructing the travel of the material which is arrested and caused to accumulate on the reef. Later it is built up by waves into a cay. It is probable that the shape of the reef has very little to do with the resulting cay, which is quite independent of its foundation. The differences existing between the sand bank or immature cay and the relatively elaborate islands with forest trees, such as Green Island, seem to be accounted for mainly in two ways—age and exposure. "No direct evidence other than size and the stage to which vegetation and beach rock are developed suggests itself for determining the age of a cay, but it is a fact that the simplest cays are often in the more exposed places. This suggests that in many cases storms and other factors have prevented the cay from attaining any size, and, even more, have given such a cay a chequered career. It must be a matter of pure luck that a sand-bank evolves into a cay: the transition stages must often be long, and the embryo cay is doubtless often washed away, and growth has to begin all over again. Where, however, there is more shelter, growth may be more or less continuous and a fully-developed cay may result."

(2) LOW WOODED ISLANDS.—These are more complex, and offer some very interesting physiographical problems. In this paper general points only are considered, as the detailed maps and descriptions of Low Isles and Three Isles made by other members of the Expedition appear elsewhere.

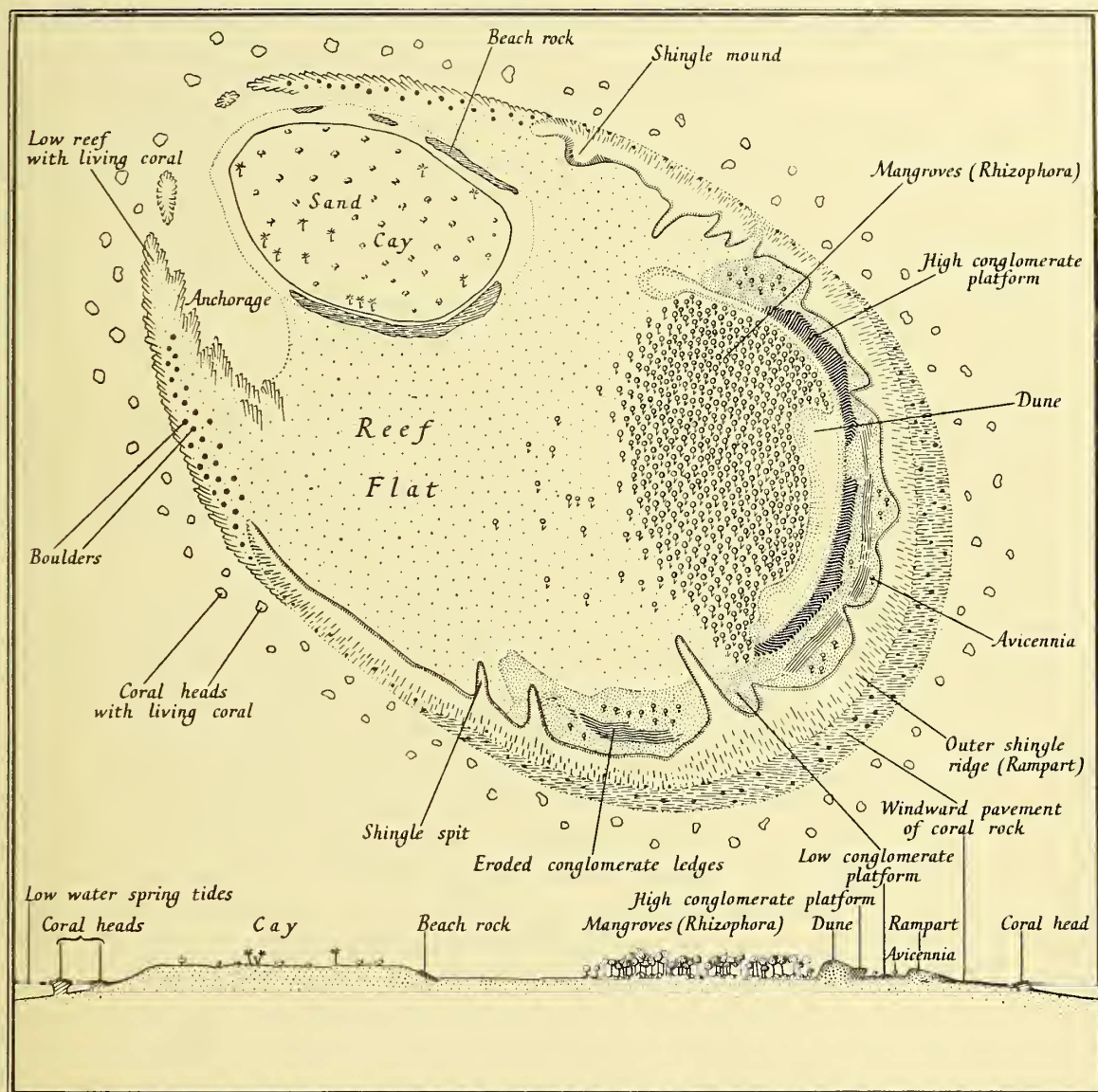
The present account will be made clearer if reference is made to the accompanying figure. This figure, which bears a considerable resemblance to Three Isles, may be taken as a *generalized* representation of a Low Wooded Island, since it is based on a reconnaissance of several such islands. In the first place it will be noticed that the figure includes two distinct regions, one of which is a sand-cay, resembling in its essential features those just described; the other consists of a series of ridges or banks of shingle (referred to in these reports as *ramparts*), in the shelter of which lies a mangrove swamp. The two together make up the Low Wooded Island of the Admiralty charts. In the normal case both the sand-cay and the shingle and mangroves occur on the same reef, but at Hope Islands the sand-cay is on one reef, the shingle and mangroves on the other. Nevertheless we may consider the two as an entity.

\* Michaelmas Cay carries vegetation, but no beach rock.



As the sand-cay so closely resembles the simple cays already described we need not give any further details here, beyond stating that it is normally more or less surrounded by beach rock, and that it usually possesses a covering of trees and plants.

The shingle "islets" are very different. There may be more than one of these, as at Three Isles, but in this case the two islets are really only discontinuous parts of a single



TEXT-FIG. 4.—Generalized sketch of a Low Wooded Island. (The vertical sides of the diagram may be taken as north-south lines.) Below is a section across the island.

series of structures. The same features, allowing for considerable individual variation, are found in all of them. On the windward side there is first the slope of the reef to deep water. Just within this we normally find ridges, or ramparts, of coral shingle. These ridges are not necessarily continuous; the outer are quite low, and slope gradually towards the sea, but steeply towards the mangroves. Inside the shingle ridges is a flat area, the *reef-flat*, which is covered at high water; and upon the surface of this flat, in the shelter of the inner ridges, lies the mangrove swamp. The shingle ridges often have narrow,

flat-topped tongues or spits running from their inner sides towards the mangroves. These, in some ways, resemble the shingle fans on the leeward sides of many shingle bars in this country, but the length, narrowness and flatness of many such on the low wooded islands renders them difficult of explanation.

The shingle ridges appear to rest upon a platform composed of coral rock, and part of this platform is visible as a rocky pavement, outside the ridges, at very low tides. This basal platform, which may be regarded as the essential "coral reef," upon which the other structures described are dependent, must not be confused with other rocky platforms at a higher level which may be found in connection with the shingle ridges. Two forms of this latter rock at least may be seen which it is reasonable to regard as stages in the development of former shingle ridges.\* The first of these may be seen on the "Inner Rampart" at Low Isles, where the shingle has become compacted into a form of "shingle conglomerate"; the second at Three Isles, where there occur platforms of very hard rock which possibly represent part of a former shingle ridge or ridges which, after having become first shingle conglomerate and then a more compact form of rock, is now being eroded.

In a case like this, where uplift has occurred (see p. 8), these erosion features are intensified.

Frequently a conglomerate platform such as that of Low Isles shows a series of inclined layers, the dip of which is irregular, but often landwards. This must mean that considerable physiographical changes have taken place, *e. g.* the removal of protecting shingle ridges. If only a landward dip shows, one may, perhaps, conclude that the rest of a spit or ridge of shingle formerly existed to seaward.

On the inner edges of these conglomerate platforms, and presumably resting upon them, one normally finds a series, more or less continuous, of modern shingle ridges, which, in some cases, are covered with sand-dunes (as at King Island). Within this system of shingle ridges and shingle-conglomerate platforms lies the mangrove belt, which is being invaded by the shingle. Although certain mangroves are found outside the mangrove swamp proper, many of them belong to a species distinct from the one which constitutes the main population of the swamp (see the account by Stephenson and Tandy). "The mangrove belt proper is a gloomy region. It is intersected by channels and lagoons which sometimes dry out at low water, leaving an expanse of black mud. Here and there openings occur, and sometimes patches of dead mangrove, which give to the place a very sinister appearance. As elsewhere, the mangroves here are partly producing their own mud, and their ramifying roots are trapping the silt brought in by the tides. There is no hard and fast line of separation between the shingle ridges and the mangrove swamp." Some of the shingle tongues push right into the mangroves, either as narrow spits or as broad flat masses, which are really recurved termini. These are often colonized by true land plants, so that in the midst of a mangrove swamp it is no rare thing to meet a small patch of scrub vegetation.

As the shingle on the outer edges of the reef is subject to wave and tidal action, mainly from the quarter between south and east, it is often found that it is driven back to form two horn-like projections, so that the entire shape assumed by the complex of ridges is that of a crescent with its convexity towards the trade wind. This is well seen at Low Isles, where the small shingle mound to the east of the cay lies at the tip of one of the horns.

\* For a fuller discussion on shingle ridges see M. A. Spender, 'Geogr. Journ.,' lxxvi, 1930, pp. 193-214, 273-297.



Between the sand-cay and the mangroves lies the reef-flat. This has been termed the "pseudo-lagoon" by some authors, but since it is in no sense a true lagoon, and simply the flat sandy top of a reef, the term "reef-flat" is adopted in these reports. At low tides this flat may dry out, only shallow pools being left upon its surface. Its surface is partly sand, partly rocky, and although the sand may extend right up to the edge of the mangrove swamp, it may be mixed with mud in this region, since the mangroves with their accompanying mud tend to spread out over the reef-flat towards the sand-cay. In many cases the reef-flat gives place on its leeward side to a deeper water zone, called the "Anchorage" (see Map of Low Isles).

In addition to the features already mentioned, large boulders, stranded by storms (Negro-Heads of some authors), are found on these reefs as well as on the outer barrier. They may occur on the windward side of inner reefs, but reach their maximum, in a case like that of Low Isles, on the leeward side of the reef, the side on which a sudden hurricane from the northward, coming in a direction opposite to that of the trade wind, does material damage to the unwieldy masses of coral accustomed to quiet water. As these islands and reefs are not exposed to the Pacific, the size of the boulders found upon them is fairly small.

If we take Low Isles as an example of the normal case of a low wooded island, we must put certain others in a separate category, *e. g.* some of the Turtle Group. The main point of difference between these and Low Isles is that the mangroves and accompanying shingle ridges are, as it were, closely wrapped round the sand-cay, the reef-flat thus being obscured. But, as in the normal case, there is a very distinct separation between the flora of the two "islets." Houghton Island, the second largest member of the Howick Group, shows similar features. Here, as in some other cases, a conglomerate platform is very well developed, and almost certainly has been upraised, *i. e.* it bears to this island, the same relationship which the low-level platforms already noted bear to the high islands and the mainland coast.

Why there should be no reef-flat between the two "islets" in these cases is not very clear. It may be that the reef on which the two are formed is too small to allow of the development of each separately, or perhaps it may mean that the mangroves have gradually spread over what was once a small reef-flat and so obliterated it. This movement has probably been accompanied by erosion on the windward side, which, in its turn, may have caused a pushing back of each successive zone.

It would seem, in either case, that the sand-cay precedes the shingle ridges and mangroves, because if we are right in assuming that the sand-cay is formed of detritus worn away from the reef, it is difficult to see how this process could go on effectively once the shingle and mangrove association has developed to windward. That the low wooded islands as a whole are characteristic of reefs some distance within the outer barrier is probably due to less wave action. The breakers of the Pacific on the outer reefs would probably be too powerful to allow of the development of shingle ridges piled above high water and, in turn, protecting a mangrove swamp.

## DESCRIPTION OF PLATE I.

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### QUEENSLAND COAST AND THE GREAT BARRIER REEFS.

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The following features referred to in the text are not shown in the map:

*Diane Bank.*

Between parallels  $15^{\circ} 42'$  S. and  $16^{\circ} 01'$  S., and longitudes  $149^{\circ} 35'$  E. and  $149^{\circ} 45'$  E.  
(Approximately  $15^{\circ} 50'$  S.,  $149^{\circ} 40'$  E.)

*Willis Islets.*

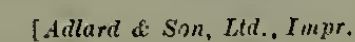
Between parallels  $16^{\circ} 7'$  S. and  $16^{\circ} 19'$  S., and longitudes  $149^{\circ} 55'$  E. and  $150^{\circ} 5'$  E.  
(Approximately  $16^{\circ} 10'$  S.,  $150^{\circ}$  E.)

*Lihou Reef.*

Between parallels  $17^{\circ} 7'$  S. and  $17^{\circ} 39'$  S., and longitudes  $151^{\circ} 17'$  E. and  $152^{\circ} 13'$  E.  
(Approximately  $17^{\circ} 20'$  S.,  $151^{\circ} 45'$  E.)

(Approximate figures are the nearest round numbers to the middle of the bank.)





DESCRIPTION OF PLATE II.

FIG. 1.—Uncliffed mainland coast just south of Archer Point.

FIG. 2.—Low-level bench on Stephen's Island (South Barnards).



GREAT BARRIER REEF EXPEDITION 1928-1929.

*Brit. Mus. (Nat. Hist.).*

REPORTS, VOL. III, No. 1.

PLATE II.



FIG. 1.



FIG. 2.

[Allard & Son, Ltd., Impr.]